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V. WALFRID EKMAN

ON THE USE OF INSULATED WATER-BOTTLES AND REVERSING THERMOMETERS

WITH 2 PLATES AND 8 FIGURES IN THE TEXT

EN COMMISSION CHEZ
ANDR. FRED. HØST & FILS
COPENHAGUE

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ON THE USE OF INSULATED WATER-BOTTLES AND REVERSING THERMOMETERS

BY

V. WALFRID EKMAN

For determining the temperature of the sea below the surface, different principles have been used.

The thermometer (or the water-sample) is either protected against changes of temperature while being hauled up, or the thermometer registers the temperature in the sea, so that it can be read after it is hauled up. Further, an electric communication with the ship may be arranged, so that the temperature can be observed directly from on board. In accordance with these different principles, the following kinds of instruments have been used for the purpose, namely:

1) So-called "slow thermometers", which are surrounded by an insulating cover that prevents them from altering their temperature appreciably, while being hauled up.
2) Insulated water-bottles of different patterns.
3) Maximum-Minimum thermometers (Miller-Casella).
4) Reversing thermometers on the principle due to Negretti and Zambra.
5) Electric resistance-thermometers.

The "slow thermometers" must hang for a very long time in the sea to attain accurately the temperature of the water. They are therefore — and on account of the adiabatic cooling which will be mentioned below — of little practical use except from stationary ships at small depths (light-ships); where they however may be convenient.

The use of maximum-minimum thermometers is restricted to those cases where the temperature steadily decreases or steadily increases with the depth. Under no circumstances do they allow of the accuracy now demanded in oceanographical measurements.

Electrical resistance- (or conductivity-) thermometers have in later times been tried with some success, particularly by MARTIN KNUDSEN [1]).

[1]) Beretning fra Kommissionen for videnskabelig Undersøgelse af de danske Farvande. Andet Bind, Hefte 3. 1900.

They have the advantage that the vertical distribution of temperature may be completely determined in a very short time; and it is to be hoped the method when more developed will be useful at moderate depths, though the necessity of insulated conducting wires might make it impracticable at great depths. Even at small depths however it is difficult to measure the depth with sufficient accuracy, because the cable is too much impelled by currents in the water. The instrument does not always give the same indication at the same temperature, and the reason for this is according to KNUDSEN not yet quite clear.

The intention of this paper is to examine critically the two methods at present most convenient and accurate, namely: with insulated water-bottles and with reversing thermometers.

Insulated water-bottles

The construction of water-bottles with thermal insulation has been subjected to many alterations, necessitated by the rapid developement of oceanic science and the increasingly repeated demands for accuracy.

In the older kinds of water-bottles the insulation was effected by solid walls of badly conducting material. This, however, introduces the inconvenience, that the water-bottle requires a considerable time to assume the temperature of the sample to be taken; and if it is not allowed to do so very accurately before it is closed, its insulating power is to some extent illusionary. This inconvenience is obviated in PETTERSSON's water-bottle [1]). He uses the sea-water itself as insulating substance. The walls of the water-bottle are made up of concentric cylinders of thin brass or celluloid — and the lid and bottom of parallel India rubber plates — so arranged as to let the water flow freely between them, as long as the water-bottle is open. When the instrument is closed, the communication between the spaces within these cylinders and plates is interrupted, and the water, on account of its large heat-capacity and very limited circulation, serves as a good insulator.

If the thermometer should be put in after the water-bottle has come up, it is impossible to prevent the insulating spaces in the lid from getting into communication with one-another and with the central chamber; and the water in them, if cooled by upper cold water-layers, will sink into the central chamber and considerably affect the indication of the thermometer. Professor NANSEN therefore adapted the Pettersson water-bottle to take down with it in its central chamber a thermometer protected against the water-pressure, and which fills

[1]) Described in The Scottish Geographical Magazine for June 1894, A review of Swedish Hydrographic Research etc., by Otto Pettersson.

up the holes in the India-rubber plates and thus separates water-tight the spaces between them. This arrangement has further the advantage that the thermometer can be read immediately after the water-bottle has come up so that the insulation is taken into account for as short time as possible.

This improvement and some important technical arrangements characterize the well-known PETTERSSON-NANSEN water-bottle now generally used in the international investigations.

Before examining the properties of this instrument, it appeared desirable to investigate the general theory of insulated water-bottles.

Adiabatic cooling of sea-water

Independently of the more or less perfect insulation of the water-bottle the temperature of the water-sample will always sink a little owing to diminution of pressure, on being raised to the surface. If $-\delta t$ be the decrease of temperature caused by a decrease of pressure $-\delta p$, at the absolute temperature T; if e be the coefficient of dilatation, c_p and ρ be the heat capacity per gram at constant pressure and the density of the substance respectively, and J the mechanical equivalent of heat, a well known formula due to Lord KELVIN gives the relation-ship

$$\frac{-\delta t}{-\delta p} = \frac{T e}{J c_p \rho}$$

or simpler, since the density of the water-sample is sensibly the same as that of the water-layers surrounding the water-bottle,

$$\frac{-\delta t}{-\delta d} = \frac{T e}{J c_p} \cdot g \ ,$$

where $-\delta d$ is the amount by which the sample is raised towards the surface, and g is gravity.

Professor NANSEN first called the attention of oceanographers to this fact and made up tables for applying the neccessary correction. In the calculation of these tables the change of e and c_p with pressure was not taken into account.

The increase of e with pressure is very considerable especially at low temperatures, as may be seen from the table below, giving 10000 e for sea-water of salinity $S = 34{\cdot}85$ ($\sigma_0 = 28$) at different depths, under the supposition that the water has the same salinity and temperature right up to the surface. In making this calculation the following formula, deduced from TAIT's experiments, namely

$$10^5 \frac{-\delta V}{V_0} = (475\,p - 13{\cdot}6\,p^2 + 0{\cdot}93\,p^3)$$
$$-(3{\cdot}36\,p - 0{\cdot}144\,p^2 + 0{\cdot}010\,p^3)\,t + (0{\cdot}035\,p + 0{\cdot}003\,p^2)\,t^2,$$

has been used, where V_0 is the volume of sea-water at atmospheric pressure, and $-\delta V$ the decrease of volume caused by an increase of pressure p measured in 100 Bars [1]). (Consequently $p = 1$ at about 1000 m. depth.) The values of e at atmospheric pressure are calculated from KNUDSEN's tables.

Depth m.	p	10000 e						
		t = −1°·5	t = 0°	t = 2°	t = 4°	t = 7°	t = 13°	t = 20°
0	0	$0{\cdot}30_0$	$0{\cdot}51_0$	$0{\cdot}77_3$	$1{\cdot}01_9$	$1{\cdot}35_8$	$1{\cdot}95_6$	$2{\cdot}56_5$
1000	1·01	$0{\cdot}63_9$	$0{\cdot}83_8$	$1{\cdot}08_6$	$1{\cdot}31_5$	$1{\cdot}63_2$	$2{\cdot}18_2$	$2{\cdot}73_8$
2000	2·03	$0{\cdot}96_1$	$1{\cdot}14_6$	$1{\cdot}37_5$	$1{\cdot}58_5$	$1{\cdot}87_7$	$2{\cdot}37_3$	$2{\cdot}86_4$
3000	3·05	$1{\cdot}27_4$	$1{\cdot}44_2$	$1{\cdot}65_0$	$1{\cdot}84_0$	$2{\cdot}10_1$	$2{\cdot}53_4$	$2{\cdot}95_2$

The change of specific heat c_p with the pressure p, is much smaller, but at the same time it is not inconsiderable. According to formulae of Lord KELVIN, founded solely upon the two fundamental principles of the dynamical theory of heat, the variation of c_p with the pressure p is

$$\frac{\partial c_p}{\partial p} = -\frac{T}{J\rho}\frac{1}{v}\frac{\partial^2 v}{\partial t^2},$$

If we take into account the change of $\frac{\partial^2 v}{\partial t^2}$ with pressure and use the value $c_p = 0{\cdot}935$ [2]) for water at atmospheric pressure and salinity 34·85, we find for sea-water at different depths d, the following values of c_p.

d	c_p					
	t = 0°	t = 2°	t = 4°	t = 7°	t = 13°	t = 20°
1000 m.	0·926	0·927	0·927	0·928	0·929	0·930
2000 -	0·918	0·919	0·920	0·921	0·923	0·925
3000 -	0·910	0·912	0·914	0·915	0·918	0·920
5000 -	0·897	0·900	0·903			
10000 -	0·872	0·877	0·883			

The curves in Fig. 1 below, give for every 200 m. depth down to 3000 m. the decrease of temperature of sea-water of salinity 34·85 on being raised to the surface. In the calculation the above-mentioned relationships between depth, pressure, coefficient of dilata-

[1]) The unit Bar = 1 megadyne per cm^2 has lately been proposed by Prof. V. BJERKNES, who has pointed out the great advantage of this unit over the "atmosphere", to which it is approximately equal.

[2]) See THOULET. Océanographie (statique) Paris 1890 p. 298.

tion, and specific heat, have been taken into account. For g and J the values 981 cm. sec^{-2} and 41900000 cm^2 gr. sec^{-2} respectively have been used.

If for instance a water-sample of temperature $t = 4°$ is taken from 1000 m., its temperature will be lowered 0·°080; by which quantity the reading corrected for thermometer errors, must be increased. The curves show that it is of no value at all to read the thermometer accurately to 0·01 of a degree, even at rather moderate depths, without noting whether the temperature is determined with an insulated water-

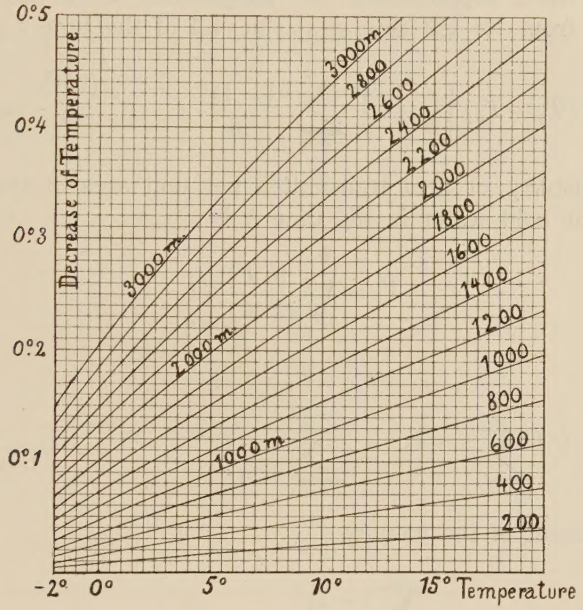

Fig. 1

bottle or with a reversing thermometer; in the former case the necessary correction must be applied. At 1000 m. depth this correction may come even into the tenths of the degree.

As an interesting fact it may be added that on raising water (of a temperature between 0° and 4°) from the greatest depth known (9636 m.) to the surface, its temperature will be lowered by about 1·°3 or 1·°4, the necessary extrapolation from Tait's measurements being too great to allow of a more accurate calculation.

Theory of insulation

The problem of calculating the flow of heat through solid walls was long ago solved mathematically. For our purpose the following very simple case is suffiicient: Imagine a plane solid wall (thickness b,

specific gravity ρ, specific heat c, conductivity k). Suppose its left side (the inside of the bottle) to be in contact with water of temperature $T = T_0$, and its right side in contact with water of temperature $T = T_1$. The temperature of the wall is initially (for $t = o$) $T = T_0$. It is required to find the quantity of heat transmitted through the wall into the water on its left in a given time. The rise of temperature in the latter (the water-sample), being very small in the time considered, may be left out of the calculation altogether. For the sake of simplicity, no account is taken of the fact that the walls of the water-bottle are actually curved.

Under these suppositions, the temperature T in the wall at a distance x from its left side is at the end of the time t given by [1]).

$$T = T_0 + (T_1 - T_0)\left[\frac{x}{b} + \frac{2}{\pi}\sum_{n=1}^{\infty}\frac{(-1)^n}{n}\, e^{-\frac{k}{\rho c}\left(\frac{n\pi}{b}\right)^2 t}\, \sin\frac{n\pi}{b}\cdot x\right]$$

The quantity of heat transmitted per unit area of the insulating wall into the cold water in the time t, is

$$V = \int_0^t k\left[\frac{\partial T}{\partial x}\right]_{x=0} dt$$

$$= \frac{k}{b}(T_1 - T_0)\, t$$

$$+ \frac{2\rho c b}{\pi^2}\left[\sum_{n=1}^{\infty}\frac{(-1)^n}{n^2} - \sum_{n=1}^{\infty}\frac{(-1)^n}{n^2}\, e^{-n^2\frac{k\pi^2 t}{\rho c b^2}}\right](T_1 - T_0)$$

On account of the identity

$$\sum_{n=1}^{\infty}\frac{(-1)^n}{n^2} = -\frac{\pi^2}{12},$$

and if

$C = \rho c b$ (= the capacity of heat per unit area of the wall)

$$\tau = \frac{k\pi^2 t}{\rho c b^2}$$

we get

$$V = \frac{k t}{b}(T_1 - T_0)\ \Phi(\tau)$$

where

$$\Phi(\tau) = 1 - \frac{2}{\tau}\left[\frac{\pi^2}{12} - e^{-\tau} + \frac{1}{4}e^{-4\tau} - \frac{1}{9}e^{-9\tau} + \frac{1}{16}e^{-16\tau} \ldots\right]$$

or

$$V = C(T_1 - T_0)\ \psi(\tau)$$

[1]) See, for instance, Riemann: Partielle Differentialgleichungen, Braunschweig 1876, p. 146.

where

$$\psi(\tau) = -\frac{1}{6} + \frac{2}{\pi^2}\left[\frac{\tau}{2} + e^{-\tau} - \frac{1}{4}e^{-4\tau} + \frac{1}{9}e^{-9\tau} - \frac{1}{16}e^{-16\tau}\ldots\ldots\right]$$

The functions $\Phi(\tau)$ and $\psi(\tau)$ are represented in Fig. 2, by the faint curve and the heavy-drawn curve respectively.

The latter curve represents on an arbitrary scale, the total amount of heat transmitted through the wall in any time; the former curve gives the ratio between this quantity and the amount of heat which would have been transmitted if the flow had been stationary during the whole time, *i. e.* if the wall had no capacity at all. The dotted

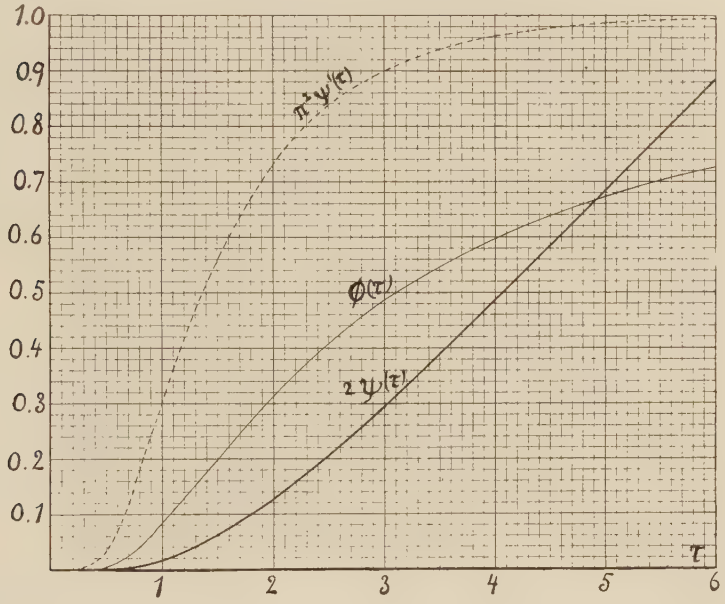

Fig. 2

curve gives the rate of transmission of heat, with its final amount as the unit.

The curves show that the quantity of heat transmitted through the wall is at the beginning exceedingly small, and only after a certain time, say $\tau = 0{\cdot}5$ or $\tau = 1\left(t = \frac{\rho c b^2}{\pi^2 k}\right)$, does it begin to increase appreciably. It is therefore essential if the wall is to insulate for as long as possible, not only to make the conductivity k small, but to make the quantity $\rho c b^2/k$ as great as possible. The time during which the wall insulates is approximately proportional to its heat-capacity per unit of volume, to its inverse conductivity, and to the square of its thickness.

At the time $\tau = 6$, the stationary state of flow has very nearly been reached, the rate of transmission of heat then differing from its final amount by less than 1 per cent.

If the insulating wall is partly or entirely made up of water-layers, heat will be transmitted by circulation in the water as well as by conduction. Some rough experiments were therefore made, to find out the insulating effect of such water-layers and solid walls combined. The experiments were made in a glass tank 30 cm. long, 15 cm. broad, and 20 cm. deep, inside. The bottom and the walls of the tank were of plate-glass of 4 or 4·5 mm. thickness. The insulating walls (15 cm. broad and 20 cm. high) were put in the tank so as to divide it into a large part A and a small part B. The volume of B was 5·1 cm^3 per square cm. of the insulating partition. The space between this and the walls of the tank, was well closed with melted bees wax so as to allow no exchange of water between the one side and the other. In the case of insulation by water-layers, the latter were enclosed between partitions of copper-plate, 1·5 mm. in thickness, which were also made water-thight as mentioned above, with bees wax. The resistance of the copper-plates against the flow of heat is quite insignificant compared to that of the insulating water-layers themselves.

Before an experiment began, A and B were filled with water (fresh-water in all experiments except No. 6) of room-temperature, and the bottom and the sides of the tank were covered by an insulating layer of cotton-wool. A cover of polished brass with apertures for thermometers, stirrers, etc., was laid on the top of it. In each of the parts A and B was a thermometer, divided in tenths, and a stirrer.

When the temperature had become quite uniform in the whole apparatus, a measured quantity of water was sucked out of A, and the same volume of hot water was quickly poured in, the water in A being constantly stirred all the while. The temperature was then observed in A and in B at different intervals of time (as a rule every 5 minutes). The water in A was stirred during the whole experiment; in B it was stirred about 20 seconds before each reading. Table I below, gives an example of such an experiment (No. 5). The numbers in the last column should obviously give the average conductivity of the partition, divided by its thickness, if the flow of heat were a stationary one. As some time is necessary for the heat to penetrate through the partition, the numbers are smaller at the beginning. When they have increased to a certain maximum (in this case 0·63), they slowly decrease on account of the imperfect insulation of B. The maximum value 0·63 is then assumed to be the definite value of K. It is easily calculated that $\tau = 5{\cdot}3$ at the beginning and $\tau = 7{\cdot}9$ at

the end of corresponding interval, and that consequently the stationary state of flow had actually been established; the last decimal place is however to be regarded as only approximate.

Table I

Hour	Temperature in A T_a	Temperature in B T_b	Interval of time in minutes t	Difference of temp. between A and B during the interval t $T_a - T_b$	Rise of temp. in B during the interval t δT	$\frac{5 \cdot 1 \, \delta T}{t(T_a - T_b)}$ K
6h 38	11·52	11·55				
50	11·54	11·55				
55	14·52	(11·55)	Hot water poured into A			
57	14·40					
59	14·36					
7h 00		11·60	5	2·85	0·05	0·018
2	14·32					
4	14·31					
5		11·75	5	2·65	0·15	0·058
9	14·24					
10		11·90	5	2·44	0·15	0·063
19	14·15					
20		12·16	10	2·16	0·26	0·061
24	14·12					
25		12·27	5	1·92	0·11	0·058
39	14·01					
40		12·54	15	1·64	0·27	0·056

Table II

Number of experiment	Construction of the insulating partition	Mean temp. of the partition	K	Resistance against flow of heat: not corrected $1/K$	Resistance against flow of heat: corrected	conductivity k
1	Only a copper-plate	12°·3	0·30	3·33		
2	One water-layer 0·27 cm. thick	12°·4	0·157	6·37	3·04	0·089
3	— — 0·55 - —	12°·5	0·107	9·35	6·02	0·091
4	— — 1·00 - —	12°·3	0·089	11·25	7·92	0·126
5	Two water-layers, each 0·57 cm. thick	13° 0	0·063	15·88	12·55	0·091
6	— — — 0·55 - — Salt-water, of spec. gravity 1·03	14°·5	0·072	13·90	10·57	0·104
7	Ebonite 0.25 cm. thick.....	11°·5	0·076	13·17	9·84	0·025
8	— 0·50 - —	10°·9	0·046	21·75	18·42	0·027

Table II gives the result of all the experiments, obtained in the same way as in the above example. In the second column is given a description of the insulating parts of the partition; the third column gives its mean temperature (the mean of the temperatures in A and B) at the moment when the value of the conductivity was recorded. The fourth column gives the values of K determined as in the example cited. The fifth column gives the reciprocal of K, i. e. the total resistance of one square cm. of the wall, against the flow of heat. As this quantity for a copper-plate 1·5 mm. thick, is only 0·003 in the units used here, the copper-plates as mentioned before, do not come under consideration at all. The first number in the fifth column is consequently the resistance against the flow of heat in A and B themselves, due to imperfect circulation of the water. By diminishing the other numbers by this value (3·33) the numbers in the sixth column are obtained, and they consequently give the resistance due solely to the partition itself. By dividing the thickness of the insulating layer by these numbers, the average conductivity of the wall in [gram-calories, cm., minutes] is obtained, and given in the seventh column.

It is seen that the ebonite insulates about 4 times as well as the water-layers. There is, however, a difference noticeable in the case of the latter, depending on their thickness. If the heat were transmitted only by conduction, the resistance would be proportional to the thickness of the wall. The circulation of the water in the insulating layer contributes, however, to the transmission of heat; and as the circulation is the less retarded by friction, the thicker the water-layer, the conductivity will be comparatively greater in a thick water-layer, than in a thin one. On comparing a water-layer of 10 mm. thickness and one of 5·5 mm., the difference is found to be rather considerable (between 0·126 and 0·091). On comparing water-layers of 5·5 and 2·7 mm. thickness, the difference is, however, very small (less than the experimental errors); which seems to denote that the circulation has no appreciable influence on the conduction of heat in water-layers of less than 5 mm. thickness. This also follows from a comparison with the values of absolute conductivity for water, given in Landolt und Börnstein's Tabellen (second edition). On taking the mean of these values for the temperatures concerned and reducing to our units [gr. cm. min.], a value of about 0·088 is obtained.

Experiment No. 6 shows that the salt-water has a greater conductivity than fresh-water. This probably depends to some extent on the greater coefficient of expansion of the salt-water; for the greater the difference of density between the water at the warm and at the cold side of the insulating water-layer, the greater will be the forces which put the water into circulation. Similarly, the insulating power

of the water-layers will then be somewhat greater at low than at high temperatures.

Since the specific heat of the ebonite per unit of volume is only 0·4, while it is about 0·96 for sea-water, the latter will insulate comparatively much better than would be supposed from the conductivities alone. From the rule at the bottom of p. 9, it is found, that ebonite would insulate for about 70 per ct. longer time than would water-layers of the same total thickness, provided the thickness of each water-layer is not more than 0·5 cm.

It is obvious from the shape of the curves for $\Phi(\tau)$ and $\psi(\tau)$ Fig. 2, that in the case of the outermost parts of the insulating wall (the parts which are first exposed to the difference of temperature) the heat-capacity is of comparatively small importance, and that their insulating effect is chiefly due to small conductivity. For the outer parts of the water-bottle, ebonite is therefore much to be preferred to water-jackets, if good insulation were the only thing to be considered.

Solid insulators should however, as has been pointed out by Professor Nansen, be used to the smallest possible extent. For they are in just the same way as the water-sample, cooled on relaxation of the pressure; and as all available good insulators have a very great coefficient of expansion, this thermal effect will be much greater than in the case of the water-sample. The latter will therefore be cooled by the walls of the water-bottle, and to a degree, which depends upon the rate of conduction of heat in the inner parts of the water-bottle, and which cannot be calculated with sufficient accuracy. This error may be very considerable at great depths; and indeed, as will be shown below, even the small quantities of ebonite and India-rubber in the Petterson-Nansen water-bottle determine the limit at which it is possible to use it with accuracy.

On the other hand solid insulating walls are inconvenient at small depths on account of the heat, which they carry down with them, and which is subsequently gradually transmitted into the water-sample, while being hauled up. The time necessary for the insulating walls to take the temperature of the sea varies as the square of the thickness.

The Petterson-Nansen water-bottle

As a description of this instrument has so far not been published, a drawing (by the maker L. M. Ericsson & Comp., Stockholm) of the latest model, now recommended, is reproduced on Plate I Figs. 1—7.

Fig. 1 shows the water-bottle open. The lid *aa* is suspended to the upper part of the frame by two hooks *b*, and under it, on the rods *y* the cylinder *h* is suspended. The thermometer guard *e*, which

is secured to the lid by means of the handle f_1, also serves as attachment for the hooks *b* and at the same time carries the air-valve f_2, which opens into the small ebonite tube *g*. The top plate *c* may be held by the springs *dd* in any one of three positions, and the hooks *b* can be put on only when it is in its middle position; when *c* has its highest position (as in the figure), it secures the hooks *b* so that they cannot let go even when worn or covered with ice. The messenger (Fig. 4) in driving the top-plate *c* (which should as indicated in the figure, be protected by a piece of leather put over the line) right down to its lowest position, presses the hooks *b* aside. The lid then falls down together with the cylinder against the bottom *ii*; the excentrics *k* are released automatically and, impelled by the load *l* of 5 kg., press the three parts of the water-bottle tightly together (Fig. 3). The hooks *j* are adjustable and should be fixed in such a position, that the excentrics can just safely pass them to be released. With the India-rubber plates *mm*, the water-bottle then closes absolutely tightly. The excentrics *k* prevent the elastic India-rubber plates from being periodically compressed and expanded, when the ship is rolling. (Without this arrangement the India-rubber plates might serve as a veritable pump steadily renewing small quantities of the sample with sea-water from the outside). Some water-bottles close rather slowly — in one half or a whole minute, because the water can escape only slowly from the inside. At a small depth (just below the surface) the moments when the water-bottle is hit by the messenger and when the excentrics are released, are easily felt on the line; and the time it is necessary to wait, after the water-bottle is hit by the messenger, before hauling up may be thus determined.

The outer part of the outlet *n* is of brass, but the rest of it, which extends upwards into the insulating parts of the water-bottle, is of ebonite. The three inner India-rubber plates *p*, of the lid and bottom, are strengthened on both sides by tinned brass-discs and are joined together by 4 ebonite-pillars *z* (Figs. 1 and 7) and brass-screws, in such a way that they may be taken off and put on as one piece, and adjusted so as to fit against the three inner cylinders *r* when the bottle is closed. The 5 concentric cylinders making up the walls of the water-bottle, are consecutively — reckoned from the centre outwards — of celluloid, brass, celluloid, brass, brass; the last one is covered with a layer of ebonite. Between the four inner cylinders are 12 strengthening pieces of ebonite, arranged in a cross (Figs. 1 and 6). The cylinders *r* and the India-rubber plates *p* are attached in such a way as to avoid continuous metallic connection between the central chamber and the water surrounding the bottle, as much as possible.

The NANSEN deep-sea thermometer *t* is fastened in position by the tightning-screw *s* and an India-rubber lining. The frame *uu* for

the reversing thermometer (see also Fig. 2) is released by the lid a hitting the lever v, and is turned round by a spiral spring in x.

The weight of the instrument with the load l but without messenger and reversing mechanism, is 16 kg.; the weight of the reversing mechanism is 1·7 kg. It takes a sample of about 440 cm³. The price is 265 kroner.

The temperature-effect in the solid walls caused by relaxation of pressure is the most serious drawback of these insulated water-bottles. The following calculation is made to give an idea of the amount to which it may arise in the Pettersson-Nansen water-bottle of the present pattern. This contains, inside the India-rubber plates *mm* and the outermost brass cylinder: 160 cm³ brass, 180 cm³ ebonite, 70 cm³ celluloid, 130 cm³ India-rubber, 17 cm³ thermometer, and the remainder, or 1650 cm³ water.

For brass we have $e = 0{\cdot}0_4 57$, $\rho = 8{\cdot}5$, $c_p = 0{\cdot}093$; and assuming that these quantities do not alter appreciably with the pressure, the brass would be cooled by about 0°·05 when hauled up from 1000 m. depth. Ebonite ($e = 0{\cdot}0_3 25$, $\rho = 1{\cdot}2$, $c_p = 0{\cdot}33$) would be cooled by 0°·42, celluloid ($e = 0{\cdot}0_3 45$, $\rho = 1{\cdot}3$, $c_p = 0{\cdot}36$) by 0°·63, India-rubber ($e = 0{\cdot}0_3 68$, $\rho = 0{\cdot}95$, $c_p = 0{\cdot}48$) by 0°·99, and the thermometer ($e = 0{\cdot}0_4 23$, $\rho c_p = 0{\cdot}41$) by 0°·04. The heat-capacity of all these parts of the water-bottle together, is $126 + 71 + 33 + 59 + 7 = 296$ gr. Cal. per degree, and when hauled up from 1000 m. depth their mean temperature would be lowered by

$$\frac{0{\cdot}05 \times 126 + 0{\cdot}42 \times 71 + 0{\cdot}63 \times 33 + 0{\cdot}99 \times 59 + 0{\cdot}04 \times 7}{296}$$

i. e. by 0°.39.

If for instance $t = 0$, the water itself would be cooled by 0°·05, and consequently the water-bottle by 0°·34 more. If the temperature differences had time to come to equilibrium inside the water-bottle, the error due to the solid parts of it, would consequently be

$$\frac{296}{1650 + 296} \times 0{\cdot}34 = 0°{\cdot}052.$$

At 10° the same error would be 0°·040 and at 20° 0°·030. If the water-bottle be hauled up from 3000 m. the same error would be 0°·15 at 0° and 0°·11 at 10° temperature. It is true that the error will be smaller because the temperature differences in the water-bottle have not time to come to equilibrium before the reading is taken; and so much the more since the differences of temperature do not exist from the beginning, but arise as the water-bottle is being hauled up. It would however be impracticable to calculate the quantity of cold transmitted into the central chamber in a given time, and there is nothing better to do than to apply a correction for half the above

calculated error (about 0°·02, for each 1000 m. depth). Owing to the great uncertainty of this correction, insulated water-bottles should not be regarded as satisfactory for work much below 1000 m., in any case whereever the temperature alters very slowly with the depth. For this reason the Central laboratory does not recommend the use of the Pettersson-Nansen water-bottle of the *larger* size, since the accuracy which can be obtained with it is not in due proportion to the higher insulating properties and consequently increased weight. If the smaller Pettersson-Nansen water-bottle is to be further improved, the most important point to turn to is certainly a considerable reduction of the quantities of India-rubber, ebonite, and celluloid, in it.

The curves in Fig. 3 p. 17 give for the Pettersson-Nansen water-bottle of the present pattern the total correction of temperature due to the cooling of the water-sample as well as of the solid parts of the water-bottle. The latter correction is, as proposed above, introduced by half its amount. The correction for depths greater than 2000 m. cannot be given with sufficient accuracy. An ordinary table is given here below for ordinary use.

Temperature of Water-sample	Correction for adiabatic cooling of water and water-bottle											
	100 m.	200 m.	300 m.	400 m.	500 m.	600 m.	700 m.	800 m.	900 m.	1000 m.	1100 m.	1200 m.
−2°	0·00	0·01	0·01	0·02	0·02	0·03	0·03	0·04	0·05	0·05	0·06	0·07
−1°	·01	·01	·02	·02	·03	·03	·04	·05	·05	·06	·07	·08
0°	·01	·01	·02	·02	·03	·04	·05	·05	·06	·07	·08	·09
1°	·01	·01	·02	·03	·04	·04	·05	·06	·07	·08	·09	·10
2°	·01	·02	·02	·03	·04	·05	·06	·07	·08	·09	·10	·11
3°	·01	·02	·03	·03	·04	·05	·06	·07	·09	·10	·11	·12
4°	·01	·02	·03	·04	·05	·06	·07	0·8	·09	·10	·11	·13
5°	·01	·02	·03	·04	·05	·06	·07	·09	·10	·11	·12	·14
6°	·01	·02	·03	·04	·06	·07	·08	·09	·11	·12	·13	·14
7°	·01	·02	·04	·05	·06	·07	·09	·10	·11	·12	·14	·15
8°	·01	·03	·04	·05	·06	·08	·09	·10	·12	·13	·15	·16
9°	·01	·03	·04	·05	·07	·08	·10	·11	·12	·14	·15	·17
10°	·01	·03	·04	·06	·07	·09	·10	·12	·13	·15	·16	·18
11°	·01	·03	·04	·06	·07	·09	·10	·12	·14	·15	·17	·19
12°	·02	·03	·05	·06	·08	·09	·11	·13	·14	·16	·18	·19
13°	·02	·03	·05	·06	·08	·10	·11	·13	·15	·17	·18	·20
14°	·02	·03	·05	·07	·08	·10	·12	·14	·15	·17	·19	·21
15°	·02	·03	·05	·07	·09	·10	·12	·14	·16	·18	·20	·22
16°	·02	·04	·05	·07	·09	·11	·13	·15	·17	·19	·20	·22
17°	·02	·04	·06	·07	·09	·11	·13	·15	·17	·19	·21	·23
18°	·02	·04	·06	0·8	·10	·12	·14	·16	·18	·20	·22	·24
19°	·02	·04	·06	·08	·10	·12	·14	·16	·18	·20	·22	·25
20°	02	·04	·06	·08	·10	·12	·14	·17	·19	·21	·23	·25

The effect of the residue of heat was measured in a series of experiments. The water-bottle with thermometer was put down open into a tub with warm water. When it had been standing there for a quarter of an hour, so that it had thoroughly taken the temperature of the water, it was quickly lifted up and for a short, measured time moved up and down in a big tub of cold water; at the end of this time it was closed and left hanging in the tub, and the gradual warming of the water from the insulating walls, observed on the thermometer. The temperature of the water in the second tub was observed with an ordinary thermometer divided in tenths, which was kept in

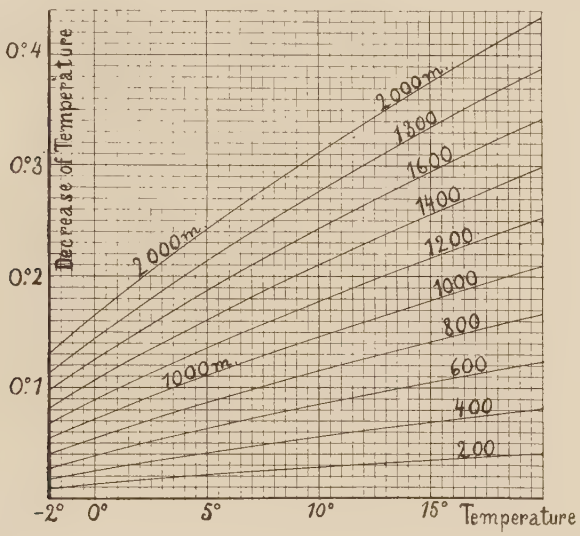

Fig. 3

motion and read off about half a minute after the closing of the water-bottle.

In the following table (p. 18) the first column gives the difference of temperature between the two water-baths, *i. e.* the initial difference of temperature between the water-bottle and the second tub. The second column gives the time in minutes during which the bottle was left open in the second tub before being closed. The next 6 columns give the rise of temperature (due to the transmission of heat from the walls of the water-bottle) 5, 10, 15, 20, 25, and 40 minutes after it was closed — or exactly, the differences between the consecutive temperature readings corrected for thermometer errors, and the temperature of the water in the tub at the moment when the water-bottle was closed.

Initial difference of temperature	time open	Effect of heat-residue after					
		5 min.	10 min.	15 min.	20 min.	25 min.	40 min.
17°·2	0·5 min.	0·10	0·19	0·26	0·30		
17°.3	1 —	0·00	0·04	0·09		0·14	0·14
15°·5	2 —	0·00	0·02	0·05	0·07	0·08	0·09

The table shows that a considerable time is required for the transmission of the heat-residue of the insulating walls into the central chamber of the water-bottle; particularly if this has been left open for some minutes, so that the thinner solid parts of it have had time to assume the temperature of the water. When the water-bottle is used at small depths (the first one or two hundred meters), the reading may easily be taken within 5 minutes; and it is then quite sufficient to keep the water-bottle open 1 minute at the depth at which it is to be closed — and particularly because the rapid change of temperature in the upper layers makes an error of one or two hunderths of a degree quite insignificant. At greater depths the change of temperature is more regular. The greater the depth to which the water-bottle is sent, the more nearly will it as a rule have already taken the temperature of the water when it arrives. Since the water-bottle is not let down much more quickly than 100 m. per minute, and since the insulation of the water-bottle cannot as a rule be relied upon for more than 10 minutes, and an error in the temperature equal to the changing temperature in half a meter of depth is of no importance at all, it may be concluded from the table that in any case likely to occur, it is sufficient to leave the water-bottle open one minute at the desired depth, before closing.

The insulating properties of the water-bottle were investigated experimentally. The water-bottle with thermometer was let down open, into a tub of water which was repeatedly stirred. After at least 15 minutes, it was closed while in the tub and then rapidly brought into another tub where it was left hanging freely in water of another temperature. The water-bottle was then raised a little out of the water every minute and the thermometer read off.

Fig. 4 represents the results of 4 of these experiments. The time is plotted horizontally, the interval between two vertical lines representing one minute; the dot at the left end of each curve corresponds to the moment at which the water-bottle was transferred from the first tub into the other. The changes of temperature after the first reading taken (1 or $^1/_2$ minute after the water-bottle was moved into the second tub), are plotted vertically upwards, either the temperature rose or fell; one interval equals 0·01 degree. The points indicated by small circles were directly observed. Below each curve

are given the initial temperature of the water-bottle (to the left) and the temperature of the water in the second tub (to the right).

The curves show — what has been already proved theoretically — that the temperature keeps nearly constant during a certain time, and then begins to change rapidly. (The small change in the reading which often takes place during the first 3 or 4 minutes, will be explained below.) The first change of temperature to which the water-bottle is exposed although small, consequently determines the time during which the insulation is effective; the changes in the uppermost water-layers even if much greater, are of less importance. Thus, for instance an increase of temperature outside, of only 1°, will probably cause the thermometer to rise 0°·02 after 15 minutes, while an increase of 10° outside will after half that time affect the reading by only a fraction of one hunderth of a degree.

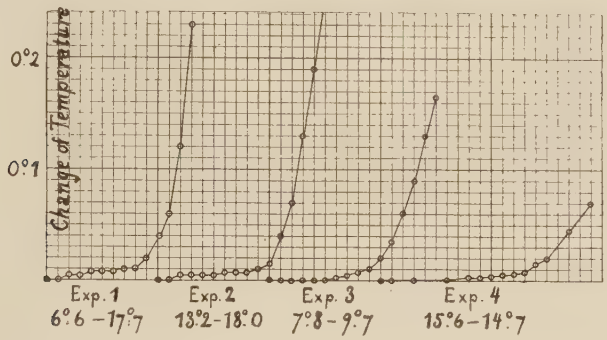

Fig. 4

The rate at which the temperature changed was, however, somewhat different under different circumstances. It seemed to increase a little with the coefficient of dilatation of the water-sample (i. e. with its temperature and salinity). The differences also often seem to be quite capricious; the diagrams in Fig. 4 may therefore be regarded chiefly as typical examples and not as representing strict rules. As might be expected, the insulation was less good, when the water-bottle was kept swinging [1]) (Exp. 3) than when it was at rest (Exp. 1, 2, 4); and furthermore the insulating effect was of course more variable in the former case than in the latter. It is therefore impossible to know a priori the time during which the insulation is effective even if the temperatures of the different water-layers tra-

[1]) When there was initially no difference of temperature inside and outside, and the water-bottle was kept in oscillatory rotations (half a turn every second), no change of temperature could be observed during 15 minutes. The heat-effect by friction between the walls of the water-bottle and the water inside, is therefore of no influence at all.

versed be rigorously taken into account. To judge from the experiments, one may, however, as a rule be quite sure for 8 or 9 minutes [1]). In doubtful cases it is to be recommended that the thermometer be read twice — immediately after the water-bottle has come up, and then one minute later. If the difference between the readings does not exceed 0°·01, the first reading may probably be regarded as correct (as far as the error due to incomplete insulation is concerned) to within one or two hunderths of a degree. This rule is however given with reservation and must be tested on the sea. One cannot rely upon it, when the water-bottle is from very great depths — more than 1000 m. say — where the cooling due to the solid walls is very considerable; for in this case the reading may, as a result of all causes together, remain constant for one or several minutes, although on account of the conduction of heat from the outside alone, there would have been a sensible change of temperature in that time [2]). It is also possible if the water-bottle comes up rapidly rotating or swinging, that the water in the inner chamber will be thoroughly mixed and thus will remain at a constant temperature for a short time after the first reading.

When the difference of temperature inside and outside was rather great, the reading changed slightly (0·01 of a degree or less) after only 2 or 3 minutes, and then remained nearly constant for several minutes (see curves 1 and 2, Fig. 4). It seems clear that this first change of reading was due to the change of temperature of the mercury-thread outside the water-bottle. This may in the worst case have a length equal to 15 degrees or about $^1/_{400}$ of the volume of the thermometer-bulb, and a difference of temperature of 4 degrees would then cause an error of 0°·01. It is hardly possible to apply the necessary correction for this error, because several minutes are required for the mercury-thread to take, even very approximately, the outer temperature, especially in the air. In the readings taken with insulated water-bottles the hundredths of the degree must therefore in most cases be regarded as only approximate. With

[1]) J. N. Nielsen has pointed out as a contributing (though probably inconsiderable) source of error, the production of heat by friction between the water-bottle and the water outside (Meddelelser fra Kommissionen for Havundersøgelser. Serie Hydrografi. Bind I No. 4). It is obvions that all temperature-differences on the surface of the water-bottle, whatever be their original cause, are transmitted towards the centre according to exactly the same law; and the only peculiarity of the frictional effect on the outside of water-bottle is that it comes into play immediately after the hauling up is began. It may however easily be calculated that this effect is quite insensible.

[2]) The difficulties which may thus arise in using insulated water-bottles at great depths, are very clearly pointed out in a paper which is about to be published by Prof. Nansen and Mr. B. Helland-Hansen.

this limitation of accuracy, the Pettersson-Nansen water-bottle may well be used — according to what is said above — down to depths of about 1000 m.

Automatic water-bottle for taking samples under-way

A new kind of insulated water-bottle with which water samples and temperatures (below the surface) may be taken from a ship in motion, has recently been designed by Prof. Nansen and the present writer (see Figs. 1—6 Pl. II).

There is no frame as in other water-bottles, but the line is attached by the bow *b* directly to the collecting tube *a*. The latter consists of 3 concentric cylinders, which enclose the insulating water-jackets (see Figs. 1 and 5). The outside cylinder is in addition covered by a layer of ebonite, 2 mm. thick. The insulation of the end-plates, which are moveable on hinges, is effected by thick India-rubber plates *d* (which serve also to tighten the closure) and by an ebonite-plate on the outside. A bathometer on Rung's principle is attached alongside the water-bottle. It consists of an air-chamber *e* Fig. 4, a brass tube *u*, a glass measuring tube *g* and a two-way tap *m*, which is operated by the rod *l*, as the bottom of the water-bottle opens and closes. When the water-bottle is open, *u* is connected with *e*, and *g* through the hole *i* with the water outside. After closing, *e* and *g* are in connection with one another. The lower end of *u* is quite open, that of *g* opens through the short brass-tube *h* to the outside water. On deck *u* and *e* are full of air, which on lowering down into the water is compressed into *e* and the upper part of *u*, to a volume depending upon the depth of immersion, so that at the actual moment of closing, this air is at the pressure of the water outside; *g* has on the way down become entirely filled with water, and is on closing connected through the tap to *e*. When the water-bottle is subsequently hauled up to the surface, the air in *e* expands into *g*, and the position of the water-meniscus indicates on the scale, the depth at which the water-bottle was closed.

An ordinary thermometer with brass mounting at its upper end, may be pushed into the spiral spring *s* in the inner cylinder (see Fig. 1) and secured by a small hook at the upper edge of the latter which fits into a hole in the mounting. The thermometer may be loosened by the finger from the hook; it is then raised by the spring sufficiently to ensure easy and convenient reading.

The ends are closed by the weight of the lead *p* (Fig. 6) which exerts a pull by means of the wheels *k* and the rods *r*. The releasing arrangement consists of a tooth *t* on each wheel, working on two discs *n*, which are rotated around a horizontal axis by the brass fan *f*.

The procedure for using the water-bottle is as follows: the ends are opened wide, the teeth *t* then push the discs *n* round and pass into the position indicated in Fig. 3. Just before letting down the water-bottle the fan is raised into the position in Fig. 1; it is then let go and the brake gently applied to avoid making kinks in the line. The fan is lifted into a position about as in Fig. 2 by hitting the water surface; and the water pressure acting on it has now to carry the weight of the lead *p*. On stopping the water-bottle by the operation of the brake, the pressure against the fan disappears, and in addition the strain effected by the lead is considerably increased; the fan therefore falls down, lets go the teeth *t*, and the water-bottle is closed (Fig. 6). Simultaneously the tap *m* of the bathometer is turned round as already explained. A catch *q* on the bottom secures the latter and thus prevents leaking.

When the water-bottle has arrived on deck, the two upper rods *r* may be pushed aside (which is possible when the water-bottle is closed, but not when it is open); the lid is opened as in Fig. 6 and the thermometer raised and read. To take the water-sample the lid is pressed down with the hand, and the plug *o* taken out; then by steadying the lid very gently, the jet of water from the tap may be regulated as desired. The water contained in the central chamber (about 200 cm^3) runs out last; the contents of the two outer water-jackets, which may possibly not be so reliable, may be used for washing. The whole sample taken is 450 cm^3.

The water-bottle insulates for 2 or 3 minutes. The bathometer has been proved quite reliable; it indicates as accurately as can be read, the same depth, no matter whether the water-bottle is let down at a moderate speed or as swiftly as possible. The accuracy with which the water-sample is collected, has also been tested. For that purpose samples were taken at 0, 1, 2, 3 and 5 meters, by an ordinary water-bottle with messenger, and afterwards at 3 meters with the automatic water-bottle. The latter was allowed to run down the first time at a moderate speed, and subsequently as swiftly as possible; in both cases samples were taken from the outer and the inner cylinders separately. The amount of Chlorine at 0, 1, 2, 3 and 5 m. was found by titration to be 13·4, 16·5, 18·03, 18·19, 18·25 respectively. The samples taken with the automatic water-bottle at 3 m. gave: in the outer cylinders 18·06 in the first case (at moderate speed), and 18·15 at high speed; in the inner cylinder 18·15 and 18·19 respectively. These numbers seem to prove that the water-bottle collects the sample accurately to within less than one meter of the depth indicated by the bathometer, and in the inner cylinder still more accurately.

The first instrument which was made, was not graduated farther than to 60 m.; down to this depth samples were easily taken while

steaming at 7 knots, and probably the instrument might have worked at even much greater depths. If the speed of the ship be slackened a little more, it is probable that the automatic water-bottle might be used down to perhaps 200 meters; but to settle this, further experiments are of course necessary.

The price of the instrument will probably be about 175 kroner.

After this was put into print, a new instrument has been made of a somewhat larger pattern, which will probably be more suitable. It has 4 concentric cylinders, insulates for 4 or 5 minutes and takes a sample of 800 cm^3. The plug *o* is exchanged for a tap. The price will be about 200 kroner.

Reversing Thermometers

Reversing thermometers, which register the temperature in situ, are independent of most of the above mentioned limitations to the use of insulated water-bottles, and they may consequently at any depth give quite correct indications. On the other hand, experience has shown that the very utmost possible care and skill is required in the making of these instruments, if they are to give accurate and always reliable results. Even selected instruments, which in the laboratory have worked accurately, may after having been used at sea for a time, become suddenly imperfect in different ways, and quite useless.

In what follows, I shall deal only with those made by C. Richter, Berlin (see Fig. 5 p. 24), which according to repeated experience are by far the best made [1]), and which is the only pattern which has been tested in the Central-Laboratory. The instrument is enclosed in a strong protecting tube divided by a cork stopper *a* into a lower chamber and an upper one. The lower chamber contains the thermometer bulb and some mercury to conduct the heat to the latter; the upper chamber contains the stem *b* of the reversing thermometer and the side thermometer *d*, which should give the temperature of the mercury in *b*, broken off. The reversing thermometer is now always divided into tenths; the side thermometer in whole degrees. The very ingenious arrangement of the contraction where the mercury breaks off, is shown on a large scale in Figs. 6—7. At the contraction, the capillary has a narrow appendix *e*, which at its end is thinned out to nothing. When the instrument is reversed, the mercury first leaves this appendix and then breaks off just at its mouth (Fig. 7). The S-shaped bend *s* prevents drops of mercury afterwards falling into the capillary, while the thermometer is being hauled up through warmer water-layers. By making the volume of this bend large enough, the instrument may

[1]) See for instance Zeitschrift für Instrumentenkunde 1904 p. 263: Über Tiefsee-Umkippthermometer, von Dr. Fr. Grützmacher.

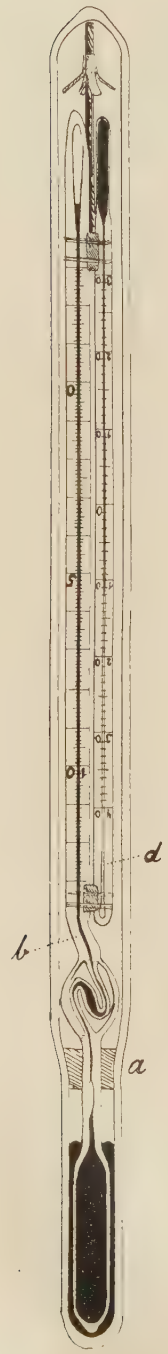

Fig. 5.

Fig. 6.

Fig. 7.

be made independent of any warming to which it may be exposed; instruments have been made for use in the tropics, in which, even after warming 50 degrees after reversal, it was impossible to shake down any mercury into the capillary. For ordinary purposes the S-bend is made smaller, so as not to have an unnecessarily large quantity of mercury broken off and consequently a large correction for its change of temperature. The great inconvenience of the mercury getting loose from the walls of the bulb and filling the capillary, when the instrument is shaken, has been almost completely overcome in the Richter thermometers; among the considerable number of these instruments, tested in the Central Laboratory, in only two was it possible by rather hard knocking against the table to bring down the mercury.

The quickness of registering was examined in a big tub of water, in which the thermometer with its brass-tube guard was kept moving quite slowly. When the temperature of the instrument was initially 10° different from that of the water, it took the temperature of the latter to within 1 degree in half a minute, to within 0°·1 in 1 minute, to within 0°·02 in $2^1/_2$ minutes, and to within a few thousandths of a degree in 5 minutes. For ordinary oceanographical purposes it is therefore quite sufficient to wait 5 minutes before reversing the thermometer; and if only the tenths of the degree are desired, 2 minutes are sufficient. When we consider the greater speed with which the non-insulated water-bottles can be easily hauled up, the additional time required for registering by the reversing as compared with the

ordinary kind of thermometer seems to be rather inconsiderable. For work in the upper water-layers down to 100 or 200 m. a reversing thermometer not protected for pressure would be suitable; such a thermometer would record in one or half a minute, and the correction for pressure, which would be something about 0°·01 per meter, could be applied with sufficient accuracy, by means of a table calculated for each thermometer separately.

The coefficient of apparent dilatation of mercury in Jena glass 16^{III} is 1/6300, and in Jena glass 59^{III} 1/6100. If then the mercury broken off has a volume corresponding to n degrees *i. e.* n/6300 or n/6100 of the whole quantity of mercury, an increase of its temperature of $t°$ will cause an increase of the reading of tn/6300 or tn/6100 degrees respectively. The quantity n is of course equal to the temperature at which the thermometer was reversed + the quantity of mercury which would be broken off at zero; the latter quantity V^0 ("Volumen bis 0°") is written on the stem of each instrument. It is as a rule between 60° and 100°, and for temperatures between 0° and 20° the stem-correction is consequently between 0°·01 and 0°·02 per degree difference between the temperature read off and the temperature of the broken-off mercury. That the temperature of the latter is given with quite sufficient accuracy by the side thermometer is shown by the table below. The thermometer Richter 539 of Jena glass 16^{III} (Volumen bis 0° = 69°) was reversed at 18°·085 and was then alternately put in cold and warm water or in the air, and read off 2 or 3 times a minute. Column *A* in the table below contains the reading of the reversing thermometer, column *B* the simultaneous reading of the side-thermometer, and column *C* the former of these readings corrected by means of the latter one.

A	*B*	*C*
18·10	19·1	18·09
Therm. put in cold water		
18·09	18·0	18·09
·08	17·0	·09
·07	16·3	·09
·06	15·7	·09
·05	15·1	·09
·04	14·4	·09
·03	14·0	·09
Therm. put in warm water		
·03	14·7	·08
·07	18	07
·12	22·5	·06
·175	26	·07
·20	28	·06
·23	30	·07
·25	31·5	·07
·28	33	·08

A	*B*	*C*
18·29	33·9	18·07
·30	34·5	·08
·31	35·3	·075
·32	36	·08
·33	36·6	·08
·34	37	·08
·345	37·3	·08
Therm. taken up in the air		
·34	37·3	·08
·335	36·2	·09
·32	35	·09
·30	33·2	·09
·28	31·2	·10
·26	30·3	·09
·25	29·4	·10
·24	28·8	·095
·23	28·3	·09
·22	27·7	·09

For ordinarily accurate measurements it is therefore possible to rely upon the indications of the side-thermometer, by only taking care to wait, until it does not change more than 1° in a minute; the error of the corrected reading will then be smaller than 0°·01. If the very utmost possible accuracy should be obtained, one must of course wait, until the reading of the side-thermometer is practically stationary and not too far from that of the reversing thermometer — if necessary the thermometer may be placed in a water-bath before being read off.

The space between the thermometer and the protecting tube of instruments hitherto made, is not airfree. The pressure of the air thus surrounding the thermometer-bulb will alter slightly with the temperature and also as a result of the compression of the protecting tube; these circumstances will give rise to an error in the indication of the thermometer. The errors which depend upon the former cause are however of no consequence, since they are practically proportional to the differences of temperature and consequently are included in the table of corrections for the instrument. The error due to compression of the protecting tube is on the other hand greater, and increases with the depth at which the thermometer is used. There has been no opportunity hitherto of examining this error experimentally, and the writer therefore tried to make a rough calculation of its upper limit. Since the cork-stopper separating the upper and the lower part of the protecting tube must not let through any mercury, we must assume that it does not allow the differences of air-pressure on the sides of it to be levelled during the time required for one measurement, although it perhaps might, and certainly does do so in the course of time. In the instruments made by Richter, the lower part of the protecting tube has a length of 5 cm., and an outer diameter of about 12 mm.; the thickness of the glass is 1·5 or 1·25 mm., and we will assume it to be 1·25 mm. From these numbers and the coefficients of elasticity of the glass, it follows that the inner volume of this part of the tube is diminished by about 0·17 % *i. e.* by 0.006 cm^3, when the instrument is lowered 1000 m. below the water-surface. Care is now taken that there should be an air-space of at least 0·5 cm^3 (a one cm. high column of air) above the mercury in this chamber; and supposing this is of atmospheric pressure the increase of pressure on the thermometer-bulb will be 0·01 of an atmosphere; which would give rise to an error in the temperature reading of 0·°001 only. At depths of several thousand meters the error may become significant. The thermometers now made, for this reason contain inside the protecting tube air of 0·2 atmosphere pressure only; and the error due to pressure will in these instruments even at 10000 m. not exceed 0°·002. Older instruments in which there is an air-space considerably shorter than 1 cm. between the cork-stopper and the mercury in the protecting tube are not suitable for accurate measurements at depths exceeding

1000 m. They may however be easily opened and put into another tube with less mercury.

From what has been said above it is clear that well made reversing thermometers may allow of very accurate measurements, if it is only certain that the mercury always breaks off at exactly the same point. But this is obviously the chief difficulty with the reversing thermometers. Certainly those made by Richter must be regarded as of quite first-class make, and his construction of the contraction above described, has no doubt remarkable advantages over others, which have been used. During the numerous experiments with Richter thermometers in the Central Laboratory, they have when reversed in melting ice, given indications, which as a rule do not differ from one another by more than + 0°·005; and many instruments have given still more accurate indications. But nevertheless there seems to be something capricious about them, and an instrument which for a long time has worked very accurately may suddenly take to registering by as much as one or more hundredths of a degree wrong. It may happen also that an instrument suddenly begins to register quite wrongly; and after having been lying about for some time may then again work quite satisfactorily and accurately.

Against these inconveniences which probably depend on the enormous difficulty of making the thermometer sufficiently airfree and absolutely clean inside, there seems at present to be no other remedy than to have several reversing thermometers in reserve, and always to use two thermometers simultaneously. Since it is comparatively seldom that a thermometer gets wrong or gives slightly incorrect readings, it is possible in this way to get quite a sufficient guarantee as well for large as for small errors. It is of course desirable to test the instruments in melting ice as often as possible. On a new set of instruments just being made by Richter the contraction is made visible, so that its accurate working may be immediately controlled.

Reversing water-bottle

A non-insulated "reversing waterbottle", adapted for use with reversing thermometers, has been designed at the Central Laboratory. It is made in two slightly different patterns, one to be fastened in the usual way at the end of the line, the other (see Fig. 8 p. 28) to be fastened at the side of the line. Both are operated by messenger; the latter also having an arrangement for releasing a messenger below, so that any number of water-bottles may be used simultaneously on one line, in the way first proposed by Mill. The water-sample is collected in the brass-tube a (tinned inside) pivoted on an axis at b. The lids c, c^1, movable on hinges, are closed and opened on reversal of the tube a, by two pairs of eccentric rods $d\ d$ and $d^1\ d^1$. The water-bottle is sent down with the tube a

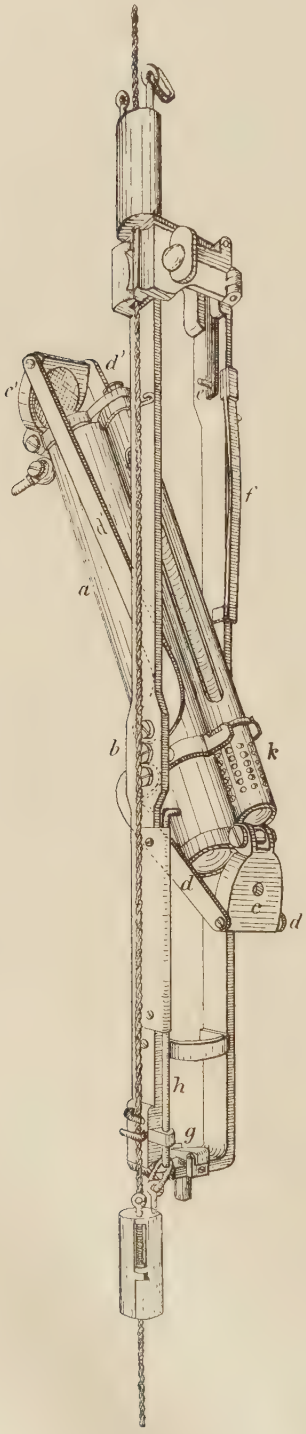

Fig. 8

in its uppermost position, where it is kept fastened by the small bolt *e*; the ends are then open, and the water runs quite unhindered straight through the tube. When the messenger arrives, the tube *a* is released, and given an impulse away from the vertical, by the spring *f*, then by its own weight it falls right down to its lowest position where it is caught and fastened by the hook *g*; the lids are then closed quite tightly. The hook *g* can catch either of two teeth on the lid c^1 according as the India-rubber packings are more or less worn. Each of these latter discs of sheet India-rubber is attached to the lid and is of the same width as the outer diameter of the tube *a*, so that there is no groove or slit where a crystal of salt might remain to vitiate the sample. The brass lids are concave inside and have a hole in the middle, to allow of the expansion of the India-rubber plates when the water-bottle closes — without this arrangement it would not close at all. The messenger below the water-bottle is attached by means of the bolt *h*, which can slide freely up and down. When the tube *a* reverses, *h* is lifted by the rod *d*, and lets go the messenger below.

The tube *a* carries side by side two brass tubes *k* for reversing thermometers, which are consequently reversed with the closing of the water-bottle. (The figure shows a somewhat older pattern, adapted for one thermometer only). The water-bottle weighs about 5 kgm., and takes a sample of about 520 cm^3. The pattern for attachment to the end of the line costs 118 kroner, the other pattern 136 kroner.

By request a larger size has also been constructed, which takes a sample of fully one liter (1070 cm^3). It is to be attached at the middle of the line, weighs 7·5 kg. and costs 165 Kr. Further, one of the former size with propeller release has also been made.

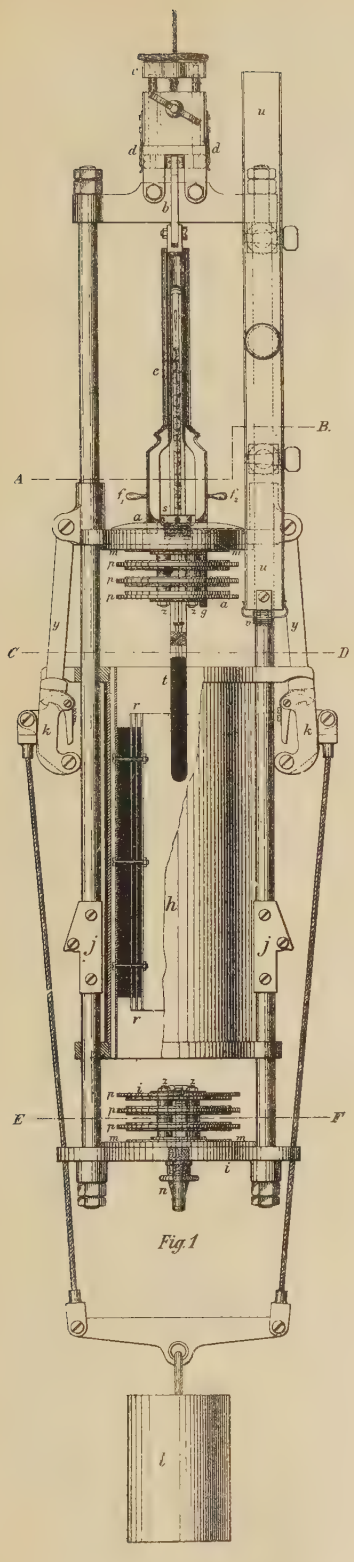

Fig.1

Fig.2

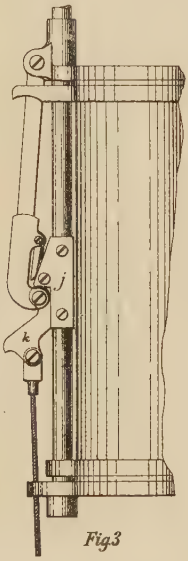

Fig.3

Fig.4

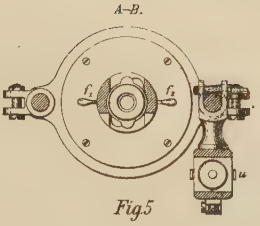

Fig.5

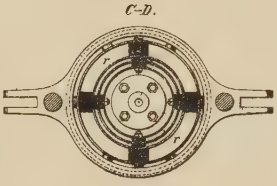

Fig.6

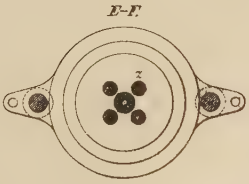

Fig.7

1:2.

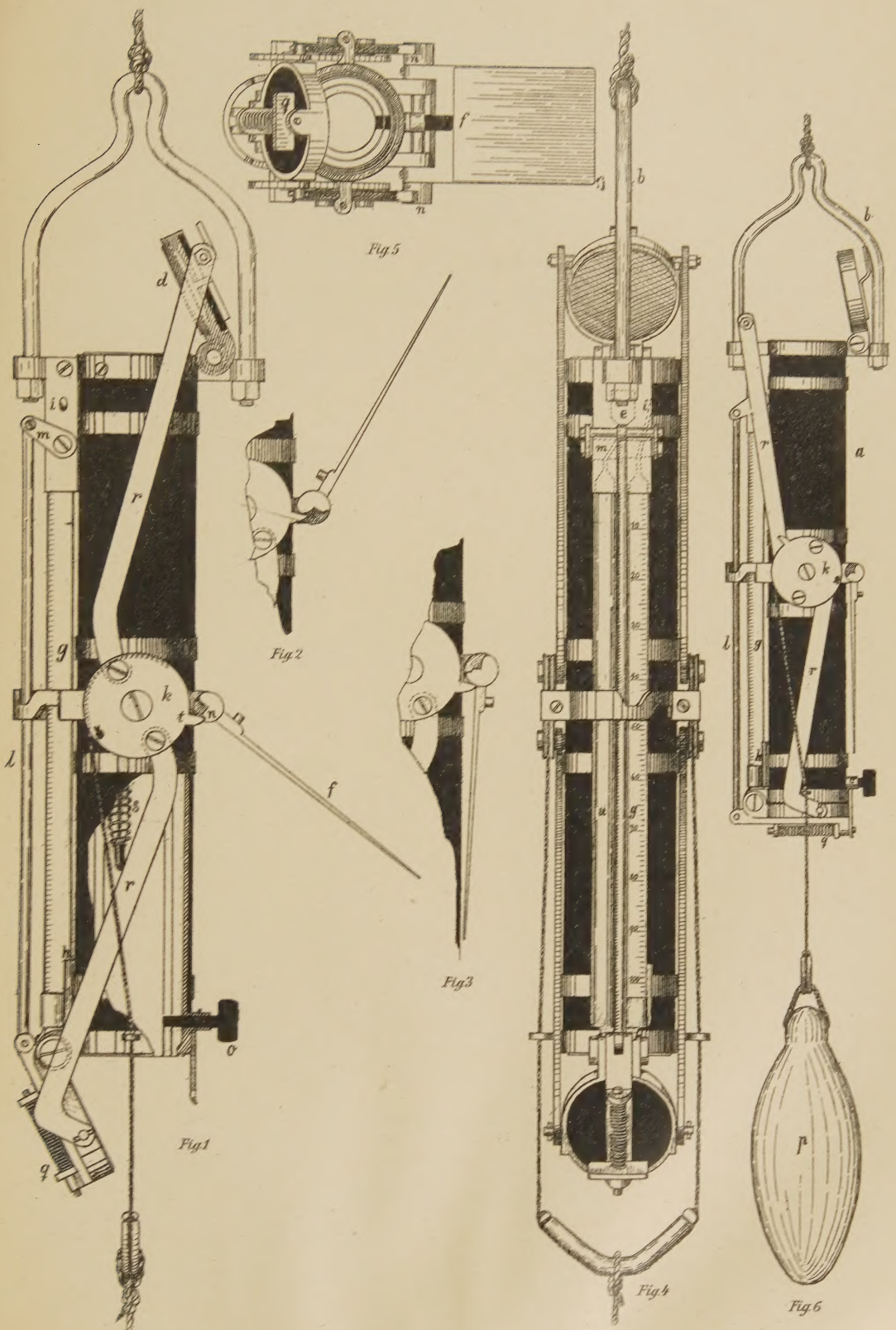
Fig.1
Fig.2
Fig.3
Fig.4
Fig.5
Fig.6

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